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Potential of using plant extracts for purification of shallow well water in Malawi

M. Pritchard [a,*], T. Mkandawire [b], A. Edmondson [a], J.G. O'Neill [c], G. Kululanga [b]

[a] Leeds Metropolitan University, School of the Built Environment, Leeds LS2 8AJ, United Kingdom
[b] University of Malawi, The Polytechnic, Department of Civil Engineering, Private Bag 303, Chichiri, Blantyre 3, Malawi
[c] Centre for Research in Environment and Health, 6 Abbotsway, York YO31 9LD, United Kingdom

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ABSTRACT

There has been very little scientific research work into the use of plant extracts to purify groundwater. Research studies on the purification of groundwater have mainly been carried out in developed countries and have focused on water purification systems using aluminium sulphate (a coagulant) and chlorine (a disinfectant). Such systems are expensive and not viable for rural communities due to abject poverty. Shallow well water, which is commonly available throughout Africa, is often grossly contaminated and usually consumed untreated. As a result, water-related diseases kill more than 5 million people every year worldwide. This research was aimed at examining natural plant extracts in order to develop inexpensive ways for rural communities to purify their groundwater.

The study involved creating an inventory of plant extracts that have been used for water and wastewater purification. A prioritisation system was derived to select the most suitable extracts, which took into account criteria such as availability, purification potential, yield and cost of extraction. Laboratory trials were undertaken on the most promising plant extracts, namely: *Moringa oleifera*, *Jatropha curcas* and Guar gum. The extracts were added to water samples obtained from five shallow wells in Malawi. The trials consisted of jar tests to assess the coagulation potential and the resulting effect on physico-chemical and microbiological parameters such as temperature, pH, turbidity and coliforms. The results showed that the addition of *M. oleifera*, *J. curcas* and Guar gum can considerably improve the quality of shallow well water. Turbidity reduction was higher for more turbid water. A reduction efficiency exceeding 90% was achieved by all three extracts on shallow well water that had a turbidity of 49 NTU. A reduction in coliforms was about 80% for all extracts. The pH of the water samples increased with dosage, but remained within acceptable levels for drinking water for all the extracts. Overall, *M. oleifera* powder produced superior results, followed by Guar gum and lastly *J. curcas*. There is a need to carry out further more detailed tests, which include toxicity to guarantee the safety of using plant extracts as a coagulant in the purification of drinking water for human consumption.

1. Introduction

About 1 billion people (15% of the world population) are without safe drinking water worldwide (UNICEF, 2009). The vast majority of these people are located in sub-Saharan Africa, South Asia and East Asia (Dungumaro, 2007 and UNICEF, 2009). Around 5 million lives are lost annually due to drinking and using contaminated water (WHO, 2006). The people at greatest risk are children, people living under unsanitary conditions and the elderly (WHO, 2006). Globally, 4 billion cases of diarrhoea are reported every year causing 1.8 million deaths, out of which about 90% are children under five (UNESCO, 2007). In Malawi, diarrhoea morbidity is around 17% (Masangwi et al., 2008).

Groundwater is the main source of drinking water for nearly 60% of the population in southern Africa (UNEP, 2002). The most common source of drinking water for the rural people in Malawi is from boreholes (deep wells), shallow wells, springs and rivers. About 37% of Malawians use boreholes as their main source of drinking water and about 26% draw their water from unprotected wells (Staines, 2002). In Malawi groundwater is usually consumed without any form of treatment (Pritchard et al., 2007; 2008). Water is a medium for thousands of microorganisms, some of which are disease-causing. Pathogens (e.g. bacteria, viruses, protozoa and helminths) in water cause a variety of diarrhoea-related diseases such as cholera, typhoid and dysentery. These pathogens are commonly derived from human faecal material. Around 2.5 billion people are without adequate sanitation in the world (UNICEF, 2009). In the rainy season, many pit latrines in the developing world collapse under their own weight due to poor workmanship which further reduces the sanitation coverage. Open defecation

* Corresponding author. Tel.: +44 7825010371; fax: +44 1138121958.
E-mail address: m.pritchard@leedsmet.ac.uk (M. Pritchard).

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in the bush and water bodies is still a popular means of human excreta disposal for rural villagers without access to pit latrines (Lungu et al., 2008). In the rainy season, faecal matter from pit latrines and open sources is washed into water bodies, thereby contaminating the water (Dzwairo et al., 2006). Microbiological water quality from shallow wells in Malawi (with depths, typically, not exceeding 15 m) has been found to be more inferior in the wet season compared to the dry season (Pritchard et al., 2007, 2008).

Conventional water purification systems using imported chemicals are prohibitively expensive for many developing countries in Africa. For example, Malawi has 52.4% of its population that live below the poverty line (GOM, 2005). Such expensive conventional methods of assuring potable water quality are unsustainable. The mortality rate arising from the use of unsafe water is a major concern for both government and international institutions throughout the world. If the Millennium Development Goals and the targets set by the World Summit on Sustainable Development are to be met, there is a vital need to develop sustainable technologies to treat groundwater for rural livelihoods. The search for locally available low cost materials therefore is inevitable.

1.1. Plant extracts for water purification

Natural plant extracts have been used for water purification for many centuries. Most of these extracts are derived from the seeds, leaves, pieces of bark or sap, roots and fruit extracts of trees and plants. For example, *Strychnos potatorum* was used as a clarifier between the 14th and 15th centuries BC. Shultz and Okun (1984) together with Sanghi et al. (2006) reported that seeds of the nirmali tree (*S. potatorum*) were used to clarify turbid river water about 4000 years ago in India. It is further reported that in Peru water has been traditionally clarified with the mucilaginous sap of tuna leaves obtained from certain species of cacti. *Zea mays* was used as a settling agent by sailors in the 16th and 17th centuries.

Laboratory, pilot-plant and full-scale studies on the performance of plant extracts such as nirmali tree (*S. potatorum*), tamarind tree (*Tamerindous indica*), guar plant (*Cyamopsis psoraloides*), red sorella plant (*Hibisicus sabdariffa*), fenugreek (*Trigonella foenum*) and lentils (*Lens esculenta*) have been conducted using raw water with turbidity that ranged from 50 to 7500 NTU (Shultz and Okun, 1984). The optimum dosage for the nirmali extract was 50 mg/l, which produced a 76% reduction in turbidity at 30 °C. The effective dose for the other extracts ranged from 2 mg/l to 20 mg/l at pH levels from 4 to 9, and proved to be more economical for turbidity values greater than 300 NTU (Shultz and Okun, 1984).

Moringa oleifera powder has been reported in literature to have the capability of reducing low and high turbidity values in surface water (Madsen et al., 1987; Muyibi and Evison, 1995; Muyibi and Okuofu, 1995). Bacterial removal in the range of 90–99% has also been reported (Madsen et al., 1987). *M. oleifera* was used as a natural coagulant in a full-scale treatment trial at the Thyolo treatment works in Malawi during the wet season of 1992. Turbidity values as high as 270–380 NTU were reduced to around four NTU, which are within the WHO (2006) guideline value with the addition of the powder (Sutherland et al., 1994).

Yongabi (2004) tested the coagulative and disinfective capabilities of *M. oleifera*, *J. curcas*, *Pleurotus tuberregium sclerotium* and *H. sabdariffa* against alum on wastewater samples. *M. oleifera* coagulated about 90% of the particles in the samples. The number of total bacterial counts reduced from 'too numerous to count' to 2700 colony forming units per ml with *M. oleifera* powder, which accounted for a 66% greater reduction than alum. *J. curcas*, *Pleurotus tuberregium sclerotium* and *H. sabdariffa* demonstrated between 60% and 90% effectiveness in purifying water samples. In particular, Yongabi (2004, p. 12) claimed that *J. curcas* seeds and calyx of *H. sabdariffa* possessed both a coagulative and a disinfective ability.

Natural coagulants have been reported to have several other advantages compared to synthetic coagulants such as alum, in that, they produce much lower sludge volume and are safe to humans. Ghebremichael (2004) reported that the sludge produced from *M. oleifera* coagulated turbid water is only 20–30% that of alum. Litherland (1995), Sanghi et al. (2006) and Katayon et al. (2006) reported that the residue of alum in water may be carcinogenic. Natural coagulants are biodegradable and cost effective for developing countries since they can be locally grown and have a wider effective dosage range for flocculation of various colloidal suspensions (Sanghi et al., 2006).

Most previous studies on the use of plant extracts have focused on surface water (e.g. Jahn, 1986; Muyibi and Evison, 1995; Sanghi et al., 2006). Also, past studies have been undertaken on *M. oleifera* and *S. potatorum*, but there are no real data on the performance of other plant extracts like *J. curcas* and Guar gum. This research therefore was aimed at establishing an inventory of the plant extracts that have been used for water purification and also to carry out preliminary tests on the performance of plant extracts available in Malawi for purification of shallow well water.

2. Materials and methods

2.1. Plant extracts

A plant extracts inventory was produced by examining the literature. The review provided the means to identify the most suitable plant extracts that have been used to treat water. The information on plant extracts included plant names, species, harvesting characteristics, where the plant is cultivated, climatic requirements, uses, estimated cost and other general information.

2.2. Sampling

Water samples were collected in 2008 from five shallow wells from Blantyre (Kumponda and Kumazale) and Chiradzulu (Nlukla, Chelewani and Mtembo) as shown in Table 1. These wells were chosen because of the high average faecal coliform counts from the previous water quality analysis by Pritchard et al. (2007) as shown in Table 2. From this previous analysis Kumponda open well registered an average faecal coliform count of 10,438 colony form-

Table 1
Well characteristics.

Well	District	Constructed/rehabilitated	Depth (m)	Approx. population served	Pump type	Coordinates[a]	
						Easting	Northing
Kumponda	Blantyre	(>20 years)	1.5	(Not used for drinking)	Open	714,378	82,70,075
Kumazale	Blantyre	2001/2004	4	200	Elephant	717,721	82,70,574
Nlukla	Chiradzulu	2004	6	700	Elephant	733,813	82,81,442
Chelewani	Chiradzulu	1998/2003	4	100	MALDA	732,869	82,80,559
Mtembo	Chiradzulu	2004	8	100	Elephant	727,946	82,73,457

[a] 1950 30th ARC DATUM.

Table 2
Total and faecal coliform results for studied wells (Pritchard et al., 2007).

Well	Total coliforms (cfu/100 ml)				Av.	SD	Faecal coliforms (cfu/100 ml)				Av.	SD
	Season						Season					
	Dry		Wet				Dry		Wet			
	August	October	February	April			August	October	February	April		
Kumazale	2	5625[a]	2340	500	947	1232	290	4775[a]	610	30	310	291
Kumponda	*3350*	*26,000*	*23,950*	*10,400*	15,925	10,871	*2600*	*8700*	*28,450*	*2000*	10,438	12,384
Chelewani	10	413	[b]	1685	703	874	0	73	1218	490	445	559
Nlukla	65	1350	4320	5820	2889	2645	35	438	1015	630	530	408
Mtembo	1000	2940	852	875	1417	1018	0	60	820	385	316	376

Italics indicate open/unprotected well – all other wells are covered/protected.
[a] Well was in state of disrepair (not being used).
[b] Results were nullified.

ing units (cfu)/100 ml. Faecal coliform counts for operational covered wells (Kumazale, Chelewani, Nlukla and Mtembo) ranged from 0 to 1218 cfu/100 ml.

Sampling equipment during this study (filtration unit, forceps, Petri dishes, pipettes and medium) were sterilised using a portable 'Express Equipment Autoclave Steamer' for 15 min at 116 °C prior to use for microbiological tests. Flaming techniques using tissue paper soaked in 70% methanol were used to sterilise water discharge points for shallow wells fitted with hand pumps for 60 s (WHO, 1997, pp. 183–184). To eliminate any stagnant water which could have stood in the service pipe, water was pumped to waste for at least 60 s (WHO, 1997, pp. 183–184). Sample bottles were rinsed three times with source water to minimise the risk of external contamination before sampling (Paqualab Manual, 2005, p. 17). For open wells, the sample bottle was held by a metallic bottle holder then plunged into the well to a depth of 0.2–0.3 m below the water level to draw the water sample (WHO, 1997, p. 186). Microbiological analysis was carried out within three hours after sampling so that the microbiological parameters did not change with time (AWWA, 1995). Initial turbidity levels of the well water were taken in the field during sampling using an 'ELE: 430–260' test meter.

2.3. Preparation of powder and solution

From the plant extract inventory *M. oleifera*, *J. curcas* and Guar gum were selected as the most suitable extracts to be considered for further study. Good quality seeds (not rotten) of the three plant extracts were individually ground using a domestic food processor. The powder was then sieved through a 600 μm sieve. The solution was then prepared by dissolving 10 g of powder in 100 ml of distilled water. An appropriate volume of solution was then measured and poured in 1000 ml of sample water to obtain the desired concentration.

2.4. Measurement of water quality parameters

Sedimentation jar tests were employed to determine the coagulation properties of the plant extracts used in this research programme. Five glass beakers of 1000 ml capacity were filled with raw water obtained from the selected shallow wells. One beaker was used as a control; the other four were dosed with each plant extract in turn, with concentrations at 50 mg/l, 100 mg/l, 250 mg/l and 500 mg/l. This dosage range was extrapolated from data published by Muyibi and Evison (1995), McConnache et al. (1999), Katayon et al. (2006). The water samples in the beakers were mixed at a high speed of 200 rpm for 60 s, as recommended by Peavy et al. (1985). Rapid mixing for a few seconds is important after adding a coagulant to obtain a uniform dispersion of the coagulant and to increase the opportunity for particle-to-particle contact. Subsequent gentle and prolonged mixing (15 min), which cements the microscopic coagulated particles into larger flocs, followed. The solution was then allowed to stand for 30 min to allow the coagulated particles to settle to the bottom. The supernatant was then poured through a Whatman filter paper No. 542 to produce a degree of filtration, i.e. to ensure that any suspended coagulant was trapped (McConnache et al., 1999). Filtration could be achieved by the use of a piece of muslin cloth at household level or a sand bed at community level. Turbidity of samples was then measured using a turbidity meter (ELE: 430–260). Faecal coliforms were determined using the membrane filtration technique. A measured volume of water, as guided by WHO (2006), was filtered through a membrane and then incubated on Membrane Lauryl Sulphate Broth (MLSB – reference OXOID MM0615) at 44 °C for 24 h. Each test was duplicated and comparable results averaged, essentially to reduce any errors related to measurement. Bacteria that were present on the membranes grew into visible colonies. The viable colonies were counted and converted to represent a count per 100 ml.

3. Results and discussion

3.1. Plant extracts inventory

Table 3 presents an inventory of plant extracts that have been historically used and documented in literature for purifying water. Quite substantial research has been conducted on the use of *M. oleifera* and *S. potatorum* as coagulants (e.g. Madsen et al., 1987; Muyibi and Evison, 1995; Muyibi and Okuofu, 1995; Ng et al., 2006). The majority of research on *J. curcas* focused on its use as a plant for producing biodiesel and very little data were available on water purification (Heller, 1996; Yongabi, 2004). Similarly, there were scanty data on all the other plant extracts such as Guar gum, *H. sabdariffa*, and *Cassia angustifolia*. Availability of the plant extracts in Malawi at the time of the study and availability of literature on use of the plant extract as a coagulant were key factors that led to the choice of the plant extracts used in the study namely; *M. oleifera*, *J. curcas* and Guar gum.

3.2. Performance of selected plant extracts

To purify water of relatively high initial turbidity, like that of Kumponda (Fig. 1a), which was 49 NTU, *M. oleifera* produced the best results, with an average percentage in turbidity reduction over the control of 96 ± 2%. The optimum dosage for *M. oleifera* was 250 mg/l with a percentage reduction in turbidity of 100%. Guar gum was ranked second at an average turbidity percentage reduction of 95 ± 1%. The optimum dosage for Guar gum was 50 mg/l,

Table 3
Plant extracts that have been used to treat water.

Extract	*M. oleifera*	*J. curcas*	*Guar gum*	*S. potatorum*	*H. sabdariffa*	*C. angustifolia*
Family name	*Moringaceae*	Euphorbiaceae	*Papilionoieae*	Loganiaceae, strychnaceae		
Botanical name/ scientific name	*M. oleifera Lam* (syns. *Moringa pterygosperma Gaertn)*	*J. curcas L.*	*Cyamopsis tetragonolobus* (L.) *Taub formerly referred to as C. psoralioides*	*S. Potatorum Linn (fam: Loganiaceae)*		
Other names	Drumstick tree, horseradish	Physic nut	Cluster bean, siam bean	Nirmali tree, Therran tree, clearing nut tree	Rosette flower, Red sorella plant, Roselle	
Local names – Malawi	Cham'mwamba, sangowa	Mtsatsimanga, Khobo		Mzaye, Kabeza	Mphesya	
Genus and species	*Moringa*	*Jatropha*	*Fabaceae*	*Strychnos*		Cassia
Countries of cultivation	India, Arabia, South East Asia, Pacific and Caribbean Islands, Central and S. America, Africa (Malawi, Tanzania, Mozambique)	Brazil, Mexico, Cape Verde, Central and South America, Caribbean, West and Central Africa, Malawi (Balaka, Dedza, Ntcheu)	India (80%), S. Africa, USA, Sudan, Pakistan (10–15%), Brazil, Malawi, Zaire, Australia	Malawi, Zambia, Zimbabwe, Botswana, Namibia, South Africa, India, Sri Lanka, Burma, Myanmar (Indo-China)	Northern Nigeria Malawi, Senegal Egypt	India
Climatic requirements	Hot, low-lying semi-arid areas, alluvial sandy soils, 100–700 m altitude, 700–2000 mm rainfall, 19–25 °C mean annual temperature	Arid and semi-arid conditions, average annual rainfall: 300–2000 mm, 0–500 m altitude, temperature range: min; −1 to 3 °C and max; 38–48 °C, well-drained alluvial sandy soils with good aeration	Tropical climate. A temperature of 70 °C is necessary for seed germination, sandy soils, moderate		Subtropical and tropical climate	
Uses	Live fencing, food, medicines, fodder, water treatment	Oil and soap production, traditional medicine, living fence, plant protectant and molluscicide, manure from seed cake	Beverage, fodder, thickening and emulsifying agent for water, soil stabiliser, flocculants, fracturing agent	Water purifier, medicinal	Medicine	Decolourisation of dye solutions, medicine
Yield	Up to 600 pods per tree from three years of age	64–3500 g per shrub	It bears many bean-like pods, each with six–nine small rounded seeds			
Height	5–15 m, laxly branched.	Up to 5 m	0.4–3 m	6–18 m		
Cost	India: US$ 30/kg Netherlands: Euro 80/kg Malawi: US$ 50/kg				41–500 USD annual income	
Toxicity	At high concentrations	Due to toxic protein (curcin) and diterpene esters	Not known	Not known	Not known	Not known
Propagation methods	From a truncheon 1–2 m high, seeds (occasionally), 1.5–6.4 m spacing	Generative propagation (seeds) and vegetative propagation (cuttings of 15–30 cm length)	Seeds (sowing is in the months of July and August)	Seeds	Seeds, 4–8 to 15–25 kg/ha sowing rate in Oct.–Dec. Harvesting leaves starts 30 days after sowing. 3–12 months of harvesting	
Limitations	Toxic at high levels	Seeds are toxic to animals (Heller (1996))				

Main references: Shultz and Okun (1984), Heller (1996), Sanghi et al. (2006) and Yongabi (2004).

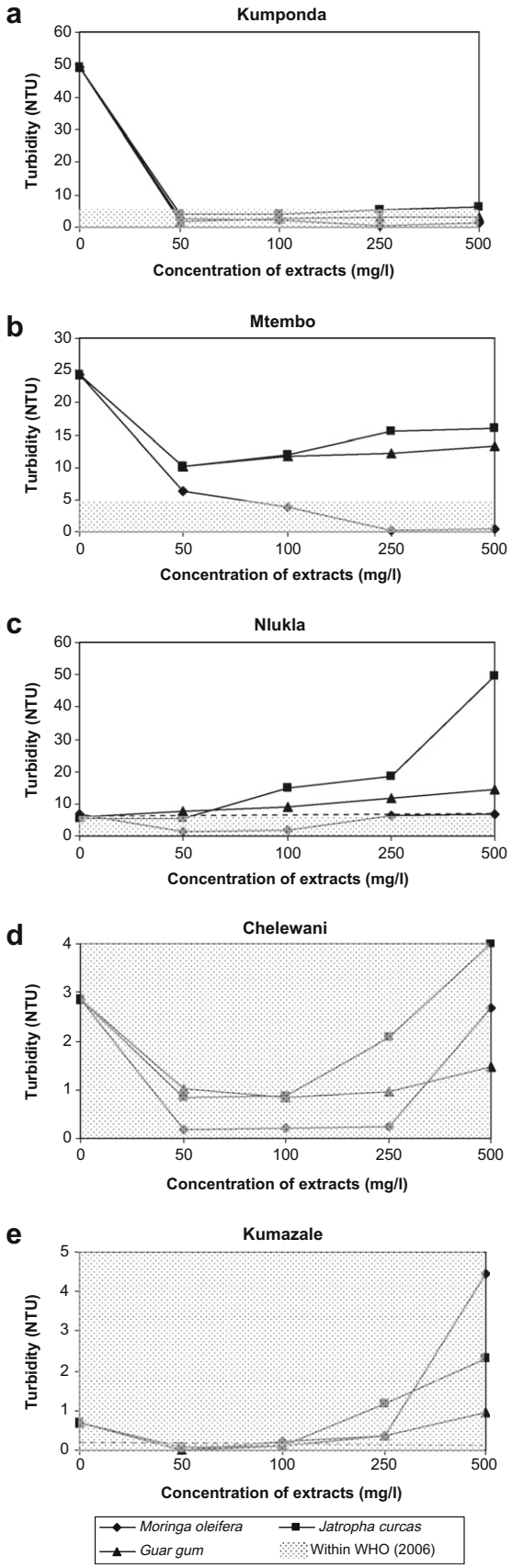

Fig. 1. (a–e) Change in turbidity of well water with plant extracts.

corresponding to a turbidity reduction of 96%. *J. curcas* had an average percentage reduction in turbidity of 90 ± 2%. The optimum dosage for *J. curcas* was also 50 mg/l with a turbidity reduction of 92%. Five times more powder was needed for *M. oleifera* to achieve optimum conditions, than Guar gum and *J. curcas*. However, it is interesting to note the optimum curve for *M. oleifera* is extremely flat and at a dose concentration of 50 mg/l a 95% reduction in turbidity was still produced, which is at least directly comparable to the other two extracts. In terms of acceptable guideline values the World Health Organisation (2006) publishes that for drinking water the turbidity should be less than 5 NTU. The shaded sections of the figures indicate whether guideline values have been reached. Apart from *J. curcas* at concentrations of 250 and 500 mg/l, all other extracts and dosage levels reduced turbidity values to within safe guideline parameters for Kumponda, with an average turbidity reduction of 94 ± 3%.

Mtembo (Fig. 1b) had an initial turbidity of 24 NTU and *M. oleifera* reduced its turbidity by an average percentage of 89 ± 12%. The optimum dosage was 250 mg/l with a turbidity reduction of 99%. Dosage above 100 mg/l produced turbidity values lower than the WHO (2006) guideline value of 5 NTU. Guar gum was ranked second with an average turbidity reduction percentage of 52 ± 5%, at an optimum dosage of 50 mg/l. Lastly, *J. curcas* reduced the turbidity of this water with an average percentage of 45 ± 12%, at an optimum dosage of 50 mg/l. However, neither Guar gum nor *J. curcas*, at any concentrations tested reduced turbidity values sufficiently to fall within the WHO (2006) guideline value.

The worst percentage reduction results for all extracts were obtained with Nlukla water (Fig. 1c), which had an initial turbidity of 7 NTU. The optimum dosage for *M. oleifera* for this water was 100 mg/l with a percentage reduction of turbidity of 75% to within the WHO (2006) guideline value. Optimum dosage for *J. curcas* was 50 mg/l, with a percentage reduction of turbidity of 10%. At higher concentration turbidity was increased. Turbidity was also increased at all Guar gum concentrations. Again Guar gum and *J. curcas failed*, at the concentration range tested, to reduce turbidity to within the WHO (2006) guideline value.

Chelewani (Fig. 1d) had an initial turbidity 3 NTU and *M. oleifera* reduced the turbidity by 93%, at an optimum concentration of 100 mg/l. At an optimum concentration of 50 mg/l, *J. curcas* reduced the turbidity by 71%, while the most favourable dosage for Guar gum was 100 mg/l, with a turbidity reduction of 71%. Even though the initial turbidity of this water was within the WHO (2006) guideline value of 5 NTU, a further reduction in turbidity was achieved for each extract at optimum conditions. With coagulation still taking place, any bacteria present in the water could be potentially reduced.

With water of very low turbidity like that of Kumazale (Fig. 1e), which had an initial turbidity of 1 NTU, an optimum dosage of 50 mg/l for all extracts was obtained. *M. oleifera* and Guar gum produced 100% turbidity reduction and an 88% reduction was noted for *J. curcas*. In reality extracts would only be used with water of such low turbidity if it can be proven that bacteria can also be removed independently of turbidity.

The pH of the water for each well was also documented throughout the testing stages (Fig. 2). The small scatter in pH values was considered irrelevant to have a significant influence on the coagulation performance from different wells. It was however noted that in 92% of the samples the pH of the water increased slightly with dose level. This trend is in agreement with *M. oleifera* results presented by Ng et al. (2006). The WHO (2006) recommends that the pH of the water should be between 6.5 and 8.5. With the addition of the plant extracts all samples were within this range. It is noted that the pH of water treated by alum decreased from 6.6 to 5.6 meaning that chemicals need to be added to raise the pH of water to the required guideline value. This procedure, hence incurred cost, is not necessary when using plant extracts as a coagulant.

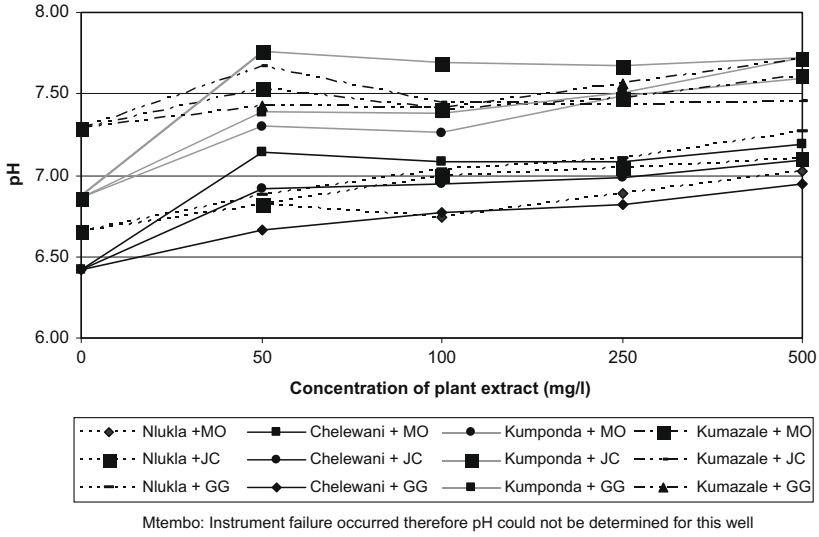

Fig. 2. Change in pH of well water samples for varying *M. oleifera* (MO), *J. curcas* (JC) and Guar gum (GG) concentrations.

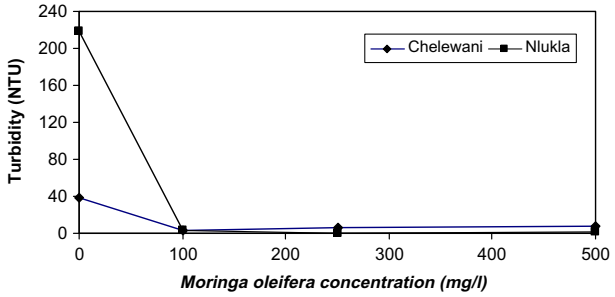

Fig. 3. Turbidity reduction of high turbid well water with *M. oleifera*.

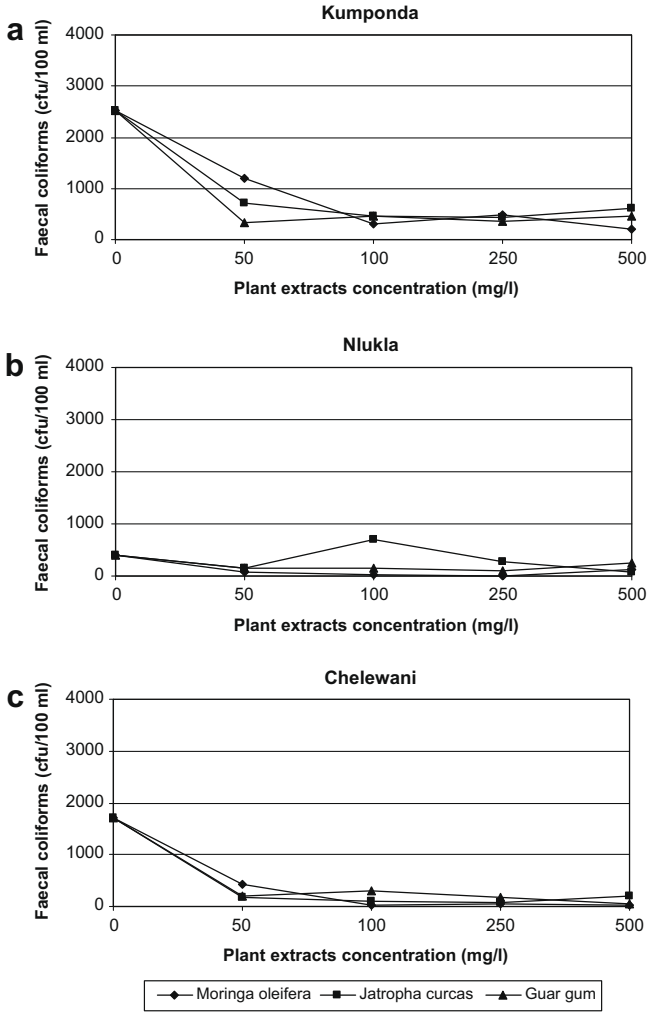

Fig. 4. (a–c) Change in faecal coliforms with extracts and dose level.

The turbidity plots for Nlukla, Chelewani and Kumazale (Fig. 1c–e) do not fit a progressional trend; however, an overall picture on what is happening can be obtained from the shape of the curves. Each of these curves are 'u' shaped in nature; even if the shape is slightly distorted for *J. curcas* and Guar gum in Fig. 1d. This shape would indicate a general trend of improvement in turbidity with low dose concentration, whilst at higher dosage the extract would tend to increase turbidity rather than reducing it. This is accounted for by the extract staying in suspension, i.e. not forming flocs and becoming sufficiently heavy to settle out. An attribute of Guar gum was that it produced very clear supernatant. Most of the solids accumulated at the bottom of the beakers, even at the highest concentration of 500 mg/l, while suspended solids could be seen with *M. oleifera* and *J. curcas*.

At relatively high turbidity levels (around 50 NTU) each extract produced similar high percentage reductions in turbidity (Fig. 1a), with *M. oleifera* being slightly better than *J. curcas* and Guar gum. At intermediate turbidity levels (around 25 NTU) *J. curcas* and Guar gum were only 50% as effective as *M. oleifera* (Fig. 1b). At low turbidity values (Fig. 1d and e), *M. oleifera* was again superior at optimum dose level than the other two extracts. Each extract performed better, in terms of percentage reductions in turbidity, the higher the initial turbidity of the water.

To ensure validity of *M. oleifera* at extremely high turbidity two of the wells (Chelewani and Nlukla) were re-sampled after a periods of prolonged rainfall. These results are presented in Fig. 3 and demonstrate that a turbidity reduction in the range of 97–100% was achieved. In particular, the water from Nlukla had an initial turbidity of 219 NTU (previously 7 NTU) and looked very turbid together with a brownish colour. At an optimum concentration of 250 mg/l *M. oleifera*, a 100% removal in turbidity occurred. At high-

er concentrations (>500 mg/l), the coagulated water had a milky colour. Turbidity reduction for Chelewani water, which had an initial turbidity of 39 NTU (previously 3 NTU) ranged from 72% to 93%, with an average of 82%. Optimum removal occurred at 100 mg/l. In each well *M. oleifera* was able to reduce turbidity to within the WHO (2006) guideline value of 5 NTU.

The reduction in coliforms with different concentrations of each extract was also determined for Kumponda, Nlukla and Chelewani to represent a range in turbidity levels (i.e. 49, 7 and 3 NTU, respectively). Only the faecal coliforms test was undertaken as it would be difficult to guarantee the source of total coliforms in water due to the non-sterility of some procedures such as the powder processing. In general, there was a significant reduction in the number of faecal coliforms with all three extracts (Fig. 4a–c). The anomaly that occurred at 100 mg/l for *J. curcas* in Fig. 4b was put down to external contamination of the sample, however further testing is recommended for confirmation. At optimum conditions each extract reduced the number of faecal coliforms by about 80%. Even though this was a significant reduction, none of the extracts were capable of reducing the faecal coliform level sufficiently to meet the WHO (2006) guideline value of zero cfu/100 ml or the Ministry of Water Development temporary guideline value for untreated water of 50 cfu/100 ml (MoWD, 2003).

4. Conclusions

- From a plant extract inventory and a laboratory testing programme *M. oleifera*, Guar gum and *J. curcas* have been identified to be the most suitable plant extracts, in that order, to improve the drinking water quality parameters from shallow wells in Malawi.
- At optimum conditions large reductions in turbidity and faecal coliforms were achieved – the higher the initial turbidity the more effective was the treatment.
- The WHO and MoWD guideline values for turbidity and pH were met with the correct plant extract dose level; although reductions in faecal coliforms were considerable, they were insufficient to fall within guideline values.

5. Recommendations

The following recommendations were made:

- There is a need to conduct more tests including total dissolved solids to verify the results obtained in this research.
- There is a need to try to optimise the reduction of faecal coliforms to ensure guideline values are met.
- More plant extracts need to be tried for their water purification properties.
- There is a need to carry out toxicity tests on the extracts.
- There is a need to develop a localised water purification system so that rural villages in Malawi can use plant extracts to improve their drinking water quality from shallow wells.

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